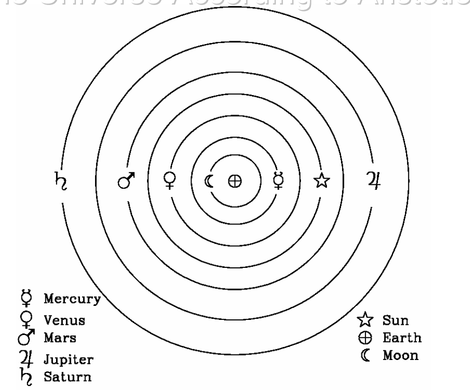
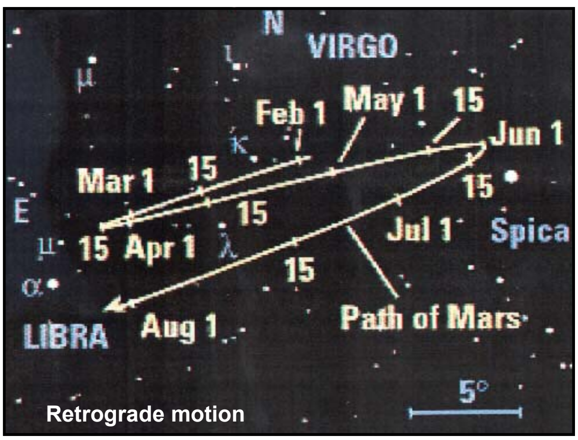
GnatSigh News
(all the news that fits)

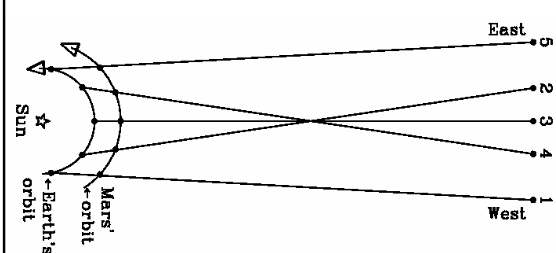
- **Final Exam 10:30-12:30 Thursday 9 June**
- **Early exam for those who asked: Tuesday 1:30-3:30pm**
  meet in my office AAC 138 (directions on website)
- **Website http://home.fnal.gov/~rocky/NS102/**
- **Study from exams & homeworks**
- **Don't memorize any equations!**
- **TA Review sessions on Tuesday and Wednesday**
  time & place to be on website

The Universe According to Aristotle

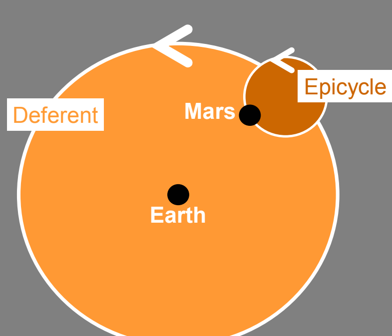




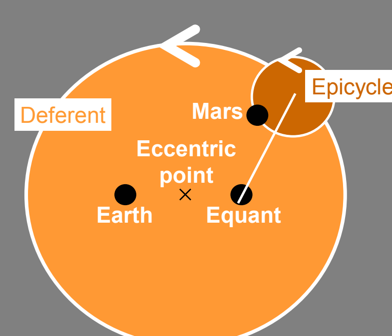
Retrograde Motion

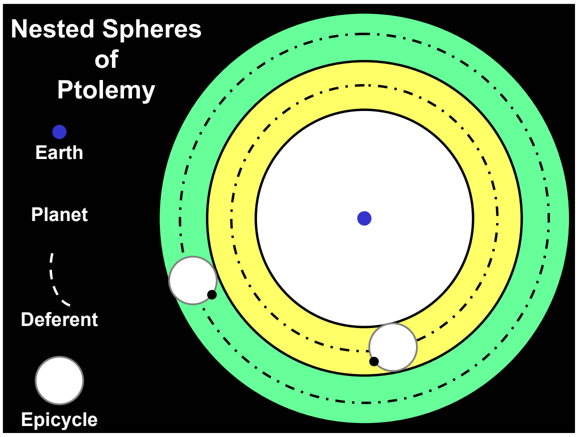


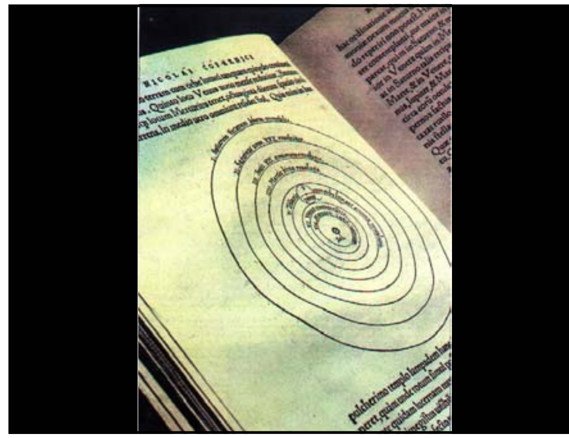
The Ptolemaic Epicycle

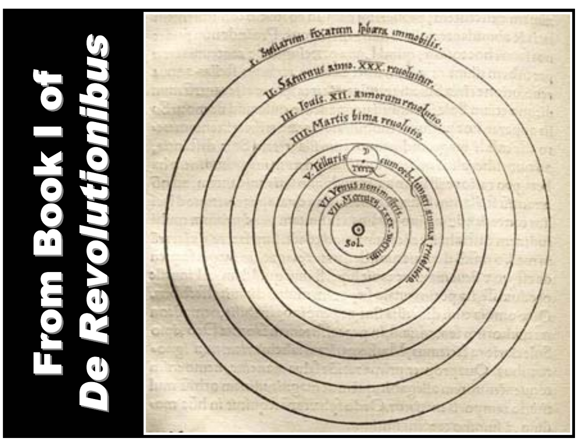


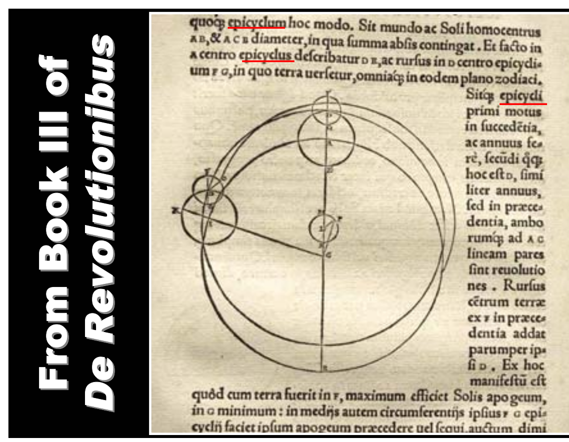
The Ptolemaic Epicycle



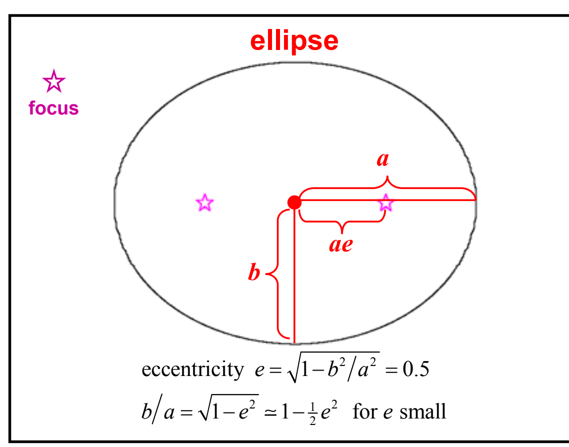

Nested Spheres of Ptolemy
Earth
Planet
Deferent
Epicycle

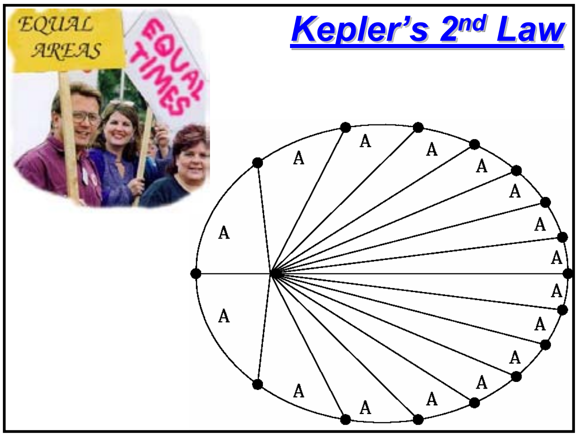


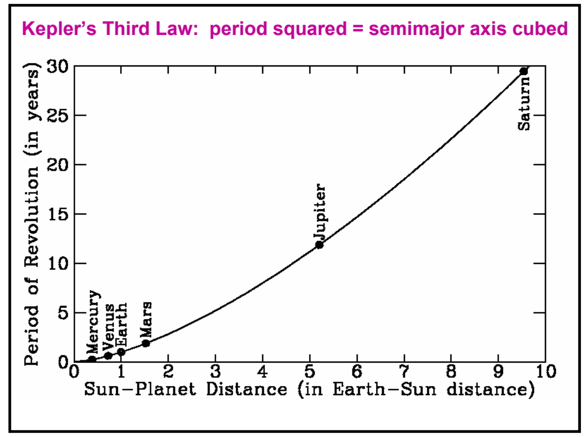

From Book I of De Revolutionibus


From Book III of De Revolutionibus


Kepler's 1st Law
...SO, YOU SEE, THE ORBIT OF A PLANET IS ELLIPTICAL
WHAT'S AN ORBIT?
WHAT'S A PLANET?
WHAT'S ELLIPTICAL?
S. harris


ellipse
focus
a
ae
b
eccentricity $e = \sqrt{1 - b^2/a^2} = 0.5$
$b/a = \sqrt{1-e^2} \simeq 1 - \frac{1}{2}e^2$ for e small





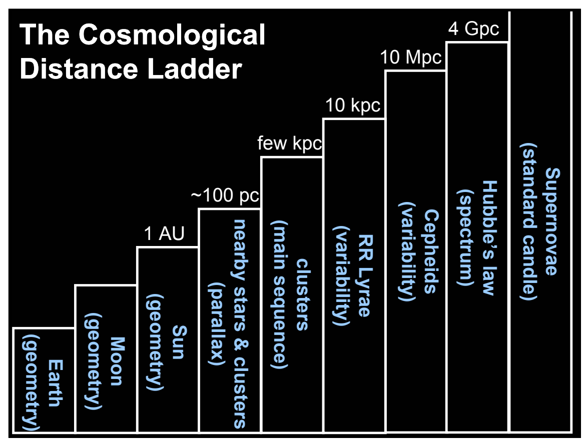
Rocky Kolb-GnatSigh Productions Presents

The Dialogue Concerning the Two Chief World Systems

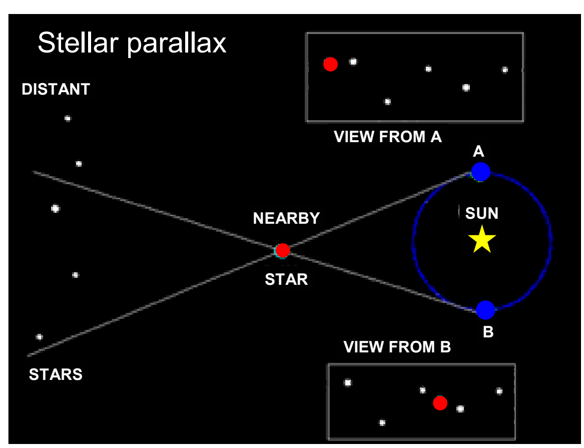
April 14, 2005

Salviati: Vanessa Tantillo
Sagredo: Talia Gorodess
Simplicio: Jeff Eisenberg

I Fantasmi: Alberto Vallinotto
Michele Liguori
Matteo Fasiello

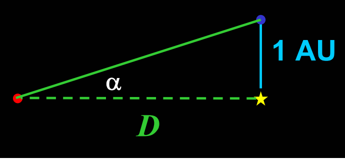


They move
They have different apparent brightness
They have different colors
They change in brightness
They (galaxies) are redshifted



$$\frac{D}{200{,}000\ \text{AU}} = \frac{\text{seconds}}{\alpha}$$

$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\alpha}$$



For light: $m_1 - m_2 = -2.5\log\left(I_1/I_2\right)$

"–" means smaller m is brighter!

Intensity of Venus vs. Sirius

Venus $m_♀ = -4$

Sirius $m_S = -1.5$

$m_♀ - m_S = -2.5\log(I_♀/I_S)$

$-4 - (-1.5) = -2.5\log(I_♀/I_S)$

$\cancel{-}2.5 = \cancel{-}2.5\log(I_♀/I_S)$

$1 = \log(I_♀/I_S)$

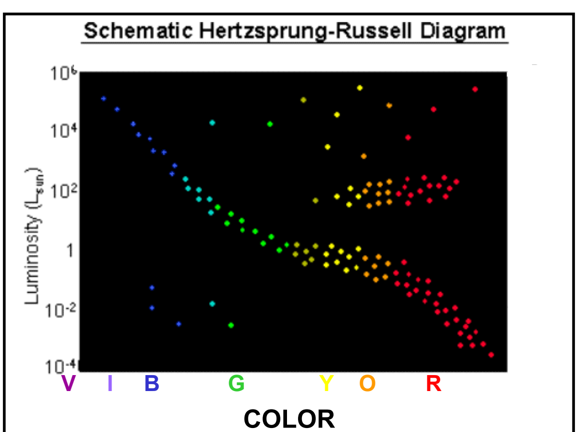
$10^1 = 10 = I_♀/I_S$

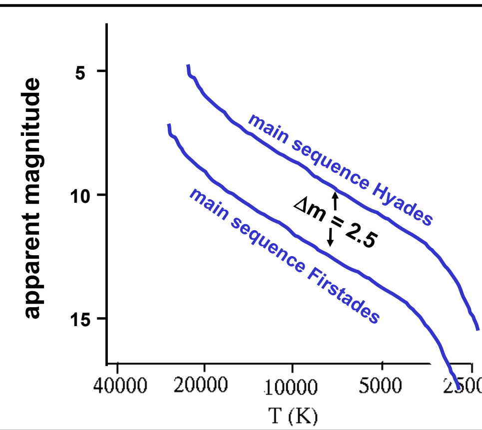
$$\frac{D}{\text{pc}} = \frac{\text{seconds}}{\text{parallax}} \qquad I = \frac{L}{4\pi R^2}$$

$$-26.8 - m = -2.5\log\left(0.137\ \text{watts cm}^{-2}/I\right)$$

Measured

star	parallax (")	distance (pc)	apparent magnitude	luminosity (solar)
α Centauri	0.75	1.3	0	1.5
Barnard's star	0.5	2.0	9.5	0.0005
Sirius	0.4	2.5	-1.5	25
Altair	0.2	5.0	0.8	10
Canopus	0.003	330	- 0.7	200,000
Arcturus	0.1	10	0	90
Betelgeuse	0.01	100	0.5	14,000





$$m_H - m_F = -2.5\log\left(I_H/I_F\right)$$

$$-2.5 = -2.5\log\left(I_H/I_F\right)$$

$$1 = \log\left(I_H/I_F\right)$$

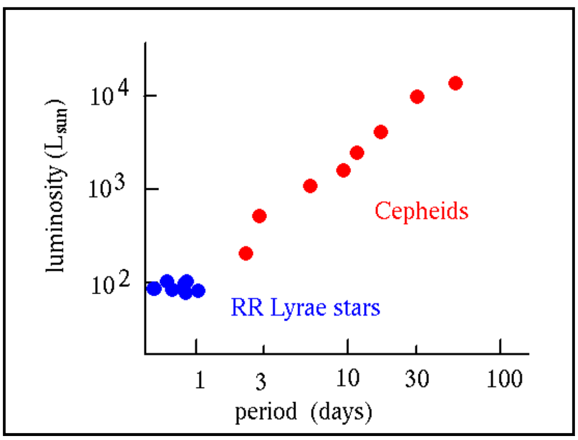
$$10 = I_H/I_F$$

$$I_H = \frac{\text{Luminosity}_H}{4\pi R_H^2} \qquad I_F = \frac{\text{Luminosity}_F}{4\pi R_F^2}$$

$$\frac{I_H}{I_F} = \frac{R_F^2}{R_H^2} \qquad 10 = \frac{R_F^2}{R_H^2} \qquad 3 = \frac{R_F}{R_H}$$

Distances to other clusters

- Construct H-R diagram for cluster
- Measure Δm compared to HR diagram for Hyades
- Compute distance in terms of distance to Hyades
- How far can you go?
- Say most distant open observable cluster is Lastades



- Main sequence stars are not extremely bright… we need brighter "standard candle"

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

- RR Lyrae stars found in distant clusters we know the distance to via H-R fitting.
- RR Lyrae stars are identified because their light output changes regularly on a time scale of half to one day.
- They are brighter than the sun by about a factor of 100 and are standard candles. Can see farther away and use as standard candle.

Cepheids as distance indicators

For cepheids of known distance

- Measure apparent magnitude of the cepheids

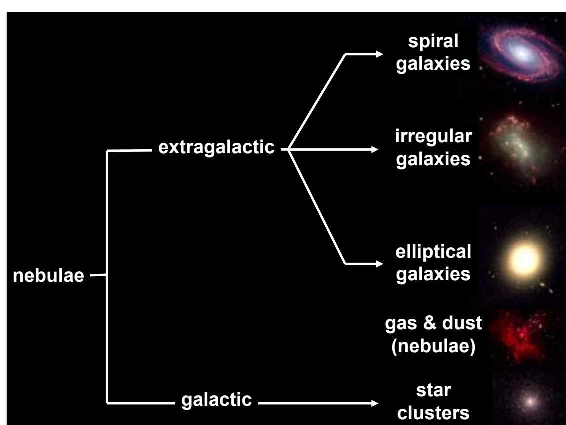
$$I = \frac{L}{4\pi R^2} \quad \rightarrow \text{know } L$$

- Measure period of the cepheids
- Calibrate (if know period know L)

For cepheids of unknown distance

- Measure period….know L
- Measure apparent magnitude

$$I = \frac{L}{4\pi R^2} \quad \rightarrow \text{know } R$$



Talking points in the Great Debate

1. Rotation of M101
2. Variable stars
3. Stars or gas
4. Spatial distribution & velocity

Doppler Shift

$\lambda_0 = c\Delta t =$ rest wavelength

$\lambda = c\ \Delta t \pm \mathrm{v}\ \Delta t =$ detected wavelength

$$c\ \Delta t = \lambda_0 \quad \Rightarrow \quad \lambda = \lambda_0 \pm \mathrm{v}\ \Delta t$$

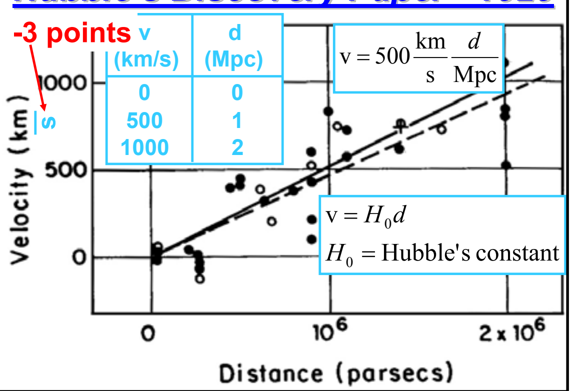
$$\Delta t = \frac{\lambda_0}{c} \quad \Rightarrow \quad \lambda = \lambda_0 \pm \frac{\mathrm{v}}{c}\lambda_0$$

$$\boxed{\lambda = \lambda_0\left(1 \pm \frac{\mathrm{v}}{c}\right)}$$

$+ \rightarrow$ receding (longer λ)
$- \rightarrow$ approaching (shorter λ)

Hubble's Discovery Paper - 1929

-3 points



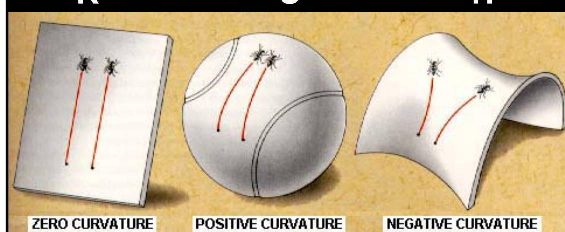
v (km/s)	d (Mpc)
0	0
500	1
1000	2

$$\mathrm{v} = 500\,\frac{\mathrm{km}}{\mathrm{s}}\,\frac{d}{\mathrm{Mpc}}$$

$\mathrm{v} = H_0 d$

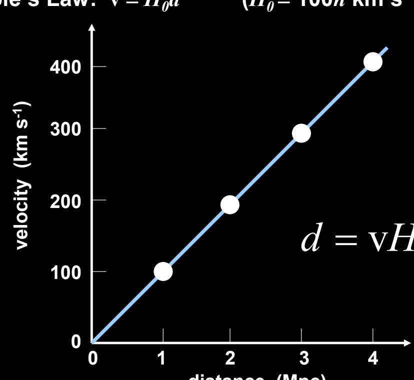
$H_0 =$ Hubble's constant

^{3}R ^{3}S ^{3}H



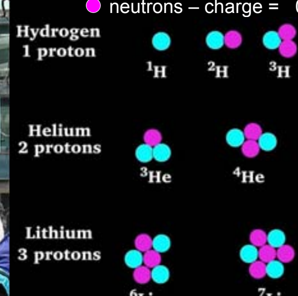
FLAT SPHERICAL HYPERBOLIC

Hubble's Law: $\mathrm{v} = H_0 d$ (H_0 = 100h km s^{-1} Mpc^{-1})



Nuclear Physics

Nucleus made of
protons – charge = +1
neutrons – charge = 0



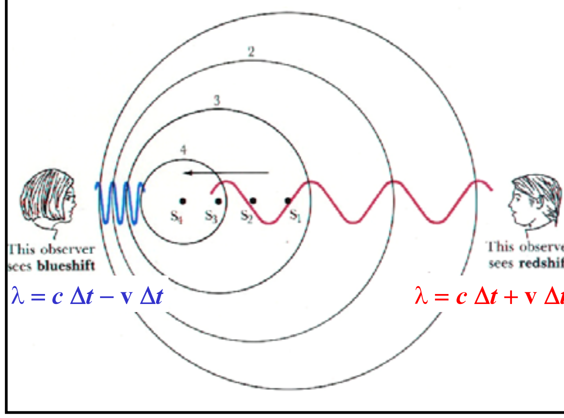
The age of the elements

- Elements come in different isotopes
  (same # of protons, different number of neutrons)
- Many isotopes are radioactive — they decay
- If start with $N(0)$ nuclei, after a time t, the number will be

$$N(t) = N(0)\, 2^{-t/\tau_{1/2}}$$

$\tau_{1/2}$ is the half-life

Can use radioactive isotopes to date objects
Radio dating …. nucleocosmochronology



We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe
  (no center)
- no special set of points
  (no edge)

The expansion of the universe is

an explosion *of* space

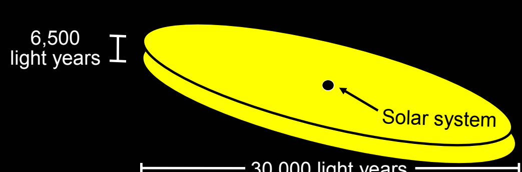
not

an explosion *into* space

The universe does not expand *into* anything!

A view of the universe, circa 1905

1) Arrangement:



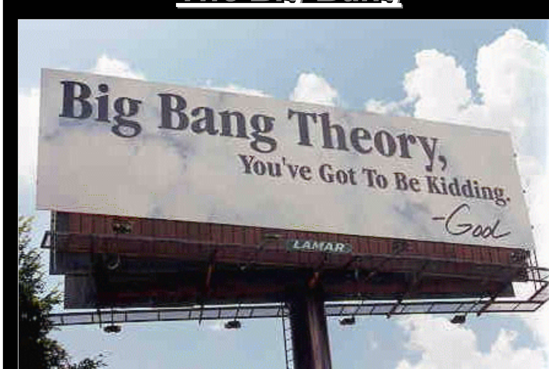
2) Composition: Starz' in the 'hood

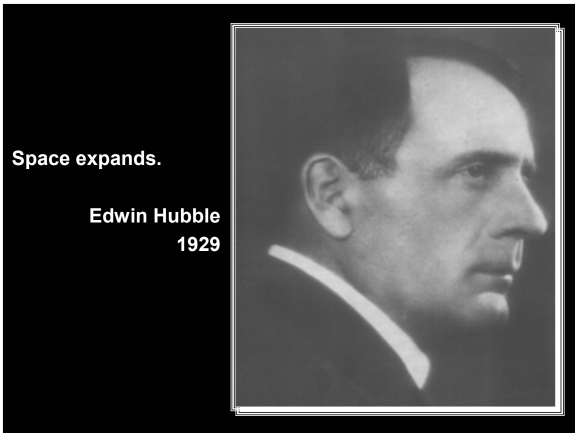
3) Static (unchanging in time)

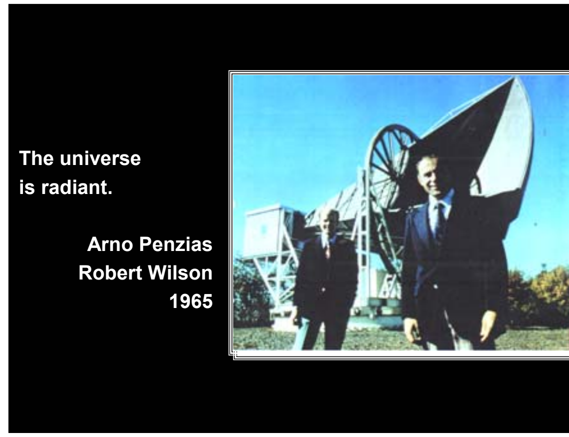
4) Origin???

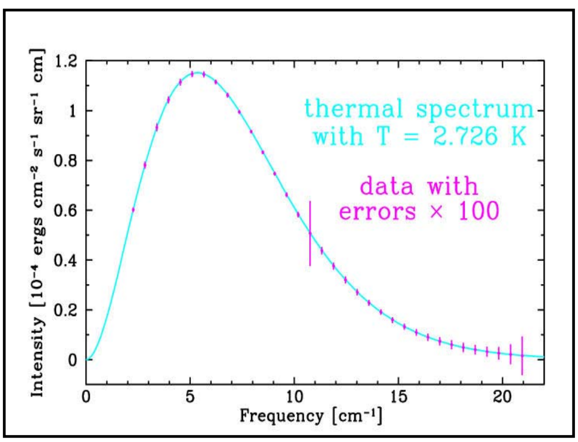
5) Space and time are absolute

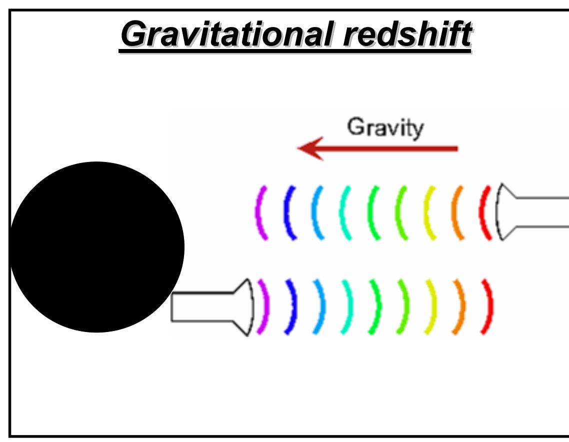
The Big Bang

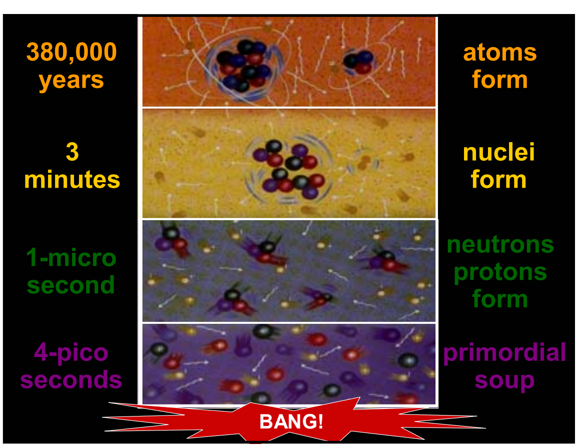


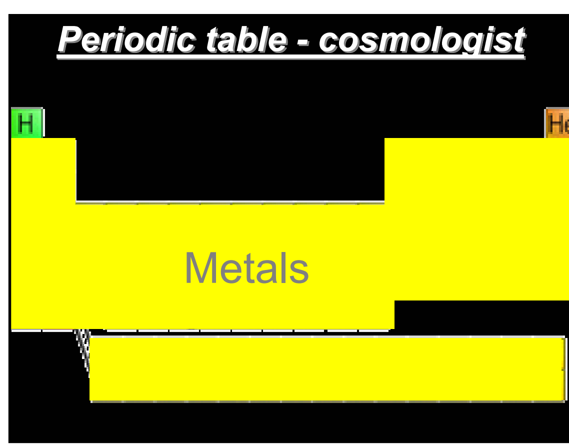

Space expands.
Edwin Hubble
1929


The universe
is radiant.
Arno Penzias
Robert Wilson
1965


thermal spectrum
with T = 2.726 K
data with
errors × 100
Intensity [10⁻⁴ ergs cm⁻² s⁻¹ sr⁻¹ cm]
Frequency [cm⁻¹]


Gravitational redshift
Gravity


380,000 years
atoms form
3 minutes
nuclei form
1-micro second
neutrons protons form
4-pico seconds
primordial soup
BANG!


Periodic table - cosmologist
H
He
Metals

Nucleosynthesis

…the process of assembling nuclei either by nuclear fusion or nuclear fission.

Big Bang nucleosynthesis (BBN): within the first three minutes of the universe and is responsible for most of the deuterium, helium-4, helium-3, and lithium-7. No elements heavier than lithium could be formed.

Stellar nucleosynthesis: creates most of the heavier elements between lithium and iron.

Supernova nucleosynthesis: produces most of the elements heavier than iron.

Cosmic ray spallation: produces some light elements like lithium and boron.

Most of the universe is dark!

It ain't even normal stuff!

Dark energy?

Space and time are related.
1905

Space is dynamical (curved, warped, bent).
1915

Empty space has a weight.
1917